International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137

Volume –06, Issue – 08, August 2021, PP – 11-21

Effect of change width of CFRP sheet on dynamic response of slab reinforce with GFRP bars

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Abstract: Reinforced concrete slabs general structural parts that may subjected to impact loads plus static loads. Reinforced concrete structures subjected to harsh environments and, because of the high corrosion, resistance of Glass Fiber Reinforced Polymer (GFRP) bars; used as a substitute for traditional steel. Up to failure, FRP bars behave in a linear-elastic manner without yielding (brittle behavior), which necessitates a solution. Recently, proposed external bonding of Carbon Fiber Reinforced Polymer (CFRP) strips on the tension side of the slab to strengthen it. In this study, the number of CFRP strips, width, and their configuration explored. Five (1550×1550×150) mm concrete slabs support all four corners of each one with simple support and reinforce with Glass Fiber Reinforce Polymer (GFRP) bars casted. Five of them externally bonded with CFRP strips. All slabs tested under impact loads by dropping a 150kg mass from a height of 5m. Two accelerometers mounted on the dropped mass measure the impact load by using Newton's second law. Displacement-time, strain-time, reaction force-time, and acceleration-time explored and compared between slabs with various configurations. The results show that increasing the number of CFRP strips with less width on the tension side of the slab develops impact resistance better.

Keywords: dynamic response, glass fibre reinforced polymer, CFRP strips, concrete slab, impact load.

1. INTRODUCTION

Building specific structures to endure both static and dynamic loads has become increasingly popular in recent years. Low-velocity high-mass impact loading circumstances common in civil engineering, and it is a type of dynamic load that includes vehicle collision-related transportation systems, Runways at airports Platforms are vulnerable to ship collisions during aircraft landings, rock falls, as well as military actions, terrorist strikes, and offshore structures. Furthermore, dynamic loading caused by natural hazards like earthquakes, which frequently linked to the effect of low velocity impact.

The behavior of a concrete structure subjected to impact loads would be very different from that of a statically loaded structure. This because the structure will vibrate during the impact and some parts of the structure may subject to tensile or compressive stresses/strains, particularly slabs, which directly sensitive to collapse under sudden loads, and this performance may because of reinforcement. Concrete slabs are slender members and that means when subjected to impact loads susceptible to flexural failure, shear failure, or both [1].

In terms of local damage (penetration, perforation and scabbing) and structural reaction in the form of flexural and shear deformations, structural deformations, and the effects of dynamic loads on the structures assessed. Under the relevant force-time history, the framework must dynamically evaluate. A revolutionary alternative and good replacement for traditional steel reinforcement for civil engineering structures is the fiber reinforced polymer (FRP) bar. The FRP bar is composed of continuous fibers made of polymeric resin embedded in a matrix. The fibers have a load carrying function; the resin has the function of linking the fibers together and moving them.FRP bars have low weight-to-strength ratios (0.2 to 0.25 of the steel density), their longitudinal tensile strength is extremely high, and non-magnetic. Although steel reinforcement has a lower initial cost than FRP reinforcement, FRP-reinforced frameworks or structural components have a lower average life cycle cost. Significantly lower maintenance expenses wanted for FRP-reinforced structural components (Reinforced Polymer Fiber).The use of FRP sheets, plates, or other materials for beams [2] and slabs [3] on the exterior surface has been widely used to strengthen structural elements. Columns that have damaged have also repaired using FRP sheets [4] FRP provides both reinforcement and containment for a damaged structure when used as external strength. Concrete beams and slabs can also reinforce with FRP bars [5] and [6] Used particularly for constructions located in coastal and salt conditions, is becoming increasingly popular. Because FRP is not an erosive substance, it has the ability to withstand rusting caused by de-icing salts. It reported that exposure to extreme circumstances, such as humidity and temperature, causes concrete's alkalinity to deplete, and the steel reinforcement corrodes as a result in RC structures, causing loss of serviceability and strength. In comparison to steel reinforcing, some important studies related to structural behavior of RC slabs with steel bars under drop weight impact loading addressed:

Turky Sami Jeddawi [7] found the distortion and failure property of slab under dynamic and static loads. Two conformable reinforced concrete (RC) with (1950 x 1950 x 100) mm dimensions are examined under same conditions. All reinforcement at top and bottom of slab are 10 M doubly reinforcement with total steel ratio (1.0 %). The static load implemented at center of the slab by using load cell with a capacity of 250 kN. The increment that used in this test to found the static load was 5 kN. The dynamic load applied on the center of the slab through the usage of a falling -weight of 475 kg from 4.15 m height with velocity impact of 9 m/s. The experimental data show that the absorption of energy of the impact loading is about 1.4 times the static loading. The biggest value of deflection found little high on the impact loading.

Tolga Yılmazan et.al. [8] Study impact behavior of two way reinforced slabs strengthened with CFRP strips by experimental work. The parameters that used in this investigation were the distributed and width of CFRP strips. The authors designed the drop-mass machine, which implemented to applied impact load. Nine slabs with (1000× 1000× 80) mm dimensions had been synthetic. Arrange of CFRP strips as orthogonally and obliquely in one and both directions with a width of (50, 100) mm. Strength eight of slab with CFRP strips and left one as control. the dynamic response and crack profiles were noticed and use the finite element program ABAQUS for molding of slabs that strengthened with CFRP then compare the results of the theoretical work and the experimental test and conclude that by using the program of finite element can found the dynamic responses of strengthened slabs .

Hesam Soltani, et al. (2020) [9] study the effect of volume fraction of steel fibers and the quantity of GFRP sheet layers and the association of GFRP sheets .a total of fourteen (1000 × 1000 × 75) mm concrete slabs reinforce with Ø8@100mm. One in all of them was slab without reinforcement and one with steel. Three of them were slabs involve steel fibers with verity volume fractions and the remain were slabs which strengthened with externally GFRP sheets or strips and dropping of (105)kg impact weight from 2.5m height. The development of crack modes of failure and dynamic behavior were study and contrast with the result of the LS-DYNA program which used to perform finite element analyses and show that raising the GFRP layer improves the impact resistance of slabs which Conclude that Slabs with completely bottom GFRP layers behavior better than those with steel fibers.

Hind Tariq Khamies (2019)[10] study, the behavior, of, slabs, strengthened, by carbon fiber, reinforced polymers CFRP bars, under impact load. Seven, specimens concrete slabs, with dimension (1550×1550) mm, three of specimens were (150) mm thicknesses, and the rest three were (120) mm thickness .all slabs reinforced, by CFRP bars with different, ratio of reinforcement, except one which, reinforced with conventional, steel bars . Thickness of slabs, and filling, mass and CFRP reinforcement, ratio were variables, parameter. Masses ranged (50 -150) kg with, diameter of 200 mm. filling from height of 2.5 m. The results found by using of high-speed data acquisition system capturing, and registration, the data at a rate of 204 kHz per channel. Dynamic responses investigate and compared for all tested specimens.

From the all above review, found aquatints of researches that take on account behavior of slabs reinforced of steel rebar under impact load with or without strengthen of FPR with a few number of researches that study the behavior of slabs reinforced with FPR rebar under impact load . There have been no researches investigate the execution of slabs reinforced with GFRP bar and externally strengthen with CFPR sheet then subjected to impact load like this research.

2. TEST SPECIMENS

At Sama Al-Nahreen Concrete Company in Baghdad, Iraq, Five slab specimens with dimensions of (1550 x 1550 x 150) mm and a 25 mm concrete cover casted and tested to evaluate the behavior of impact load on concrete slabs reinforced with GFRP bar. Single layer (bottom) of glass-reinforced bar with diameter (Ø13) and spacing of 125 mm placed in the longitudinal and transversal direction in all spacemen as shown in (table1.) and (Fig1.)Externally bonded Carbon Fiber strips used to strength four of the RC slabs, with serving one as a control specimen (CFRP). All materials, including fine and coarse aggregates and cement, designed in accordance with Iraqi specifications [11]. Based on the preliminary design according to [12], the reinforcement for the tested slabs estimated. Two criteria studied to determine the response of RC slabs strengthened with CFRP strips: the width of CFRP strips and their arrangement, which varied among the specimens. The control slab was designated by the slab symbols (SG), in which (S) refers to slab and (G) refers to slab reinforced with GFRP bar, while (SGC_n - B_m) refers to slabs reinforced with GFRP bar and strength with CFRP sheet on the bottom surface and n refer to the number of sample and m refer to the number of layer.

Table1. Details Of Test Specimens

Slab symbol	Type of reinforcement	Reinforcement (ρ) ratio%	Balanced reinforcement ratio (ρb) %	Spacing (mm)
All sample	GFRP	0. 855	0.654	Ø13@125mm

Table.2. Properties of GFRP reinforcement

Type No.	Size	Nominal Diameter (mm)	Nominal Area (mm^2)	Ultimate Tensile Load (kN)	Guaranteed Tensile Strength (MPa)	Modulus of Elasticity (GPa)
B100-13	4	13	126.7	96	**758**	46

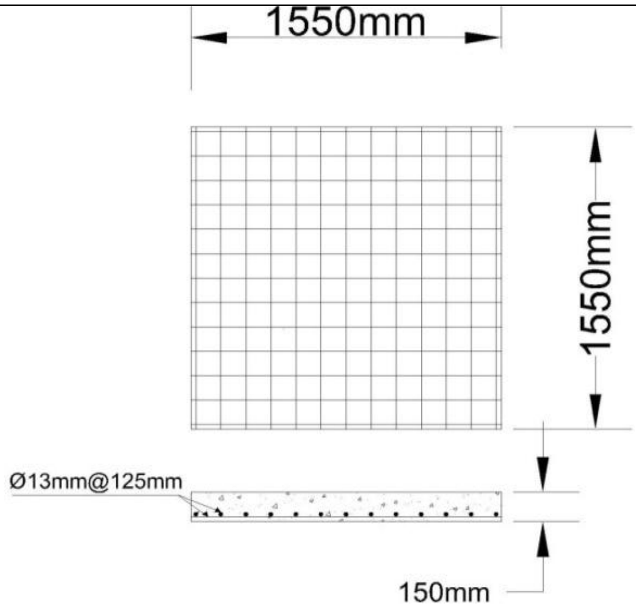


Fig.1.Test Specimens

3. CONSTRUCTION MATERIAL

In this investigation, ordinary Portland cement (type I) made in Iraq (Al Mass Company) employed. The chemical and physical properties of cement is in compliance with Iraqi standard No.5/1984 [13].As fine aggregate, Al-Ekhaider natural sand with a maximum size of 4.75mm employed and the Crushed gravel from AL-Nibaey region used for the concrete specimens with a maximum size of 10mm. The fine and crushed aggregate grading determined in accordance with Iraqi Specification No.45/1984 [14].

3.1. Glass fiber Reinforcement (GFRP) bar

Fiber reinforced plastic, also known fiber reinforced polymer, is a composite material that combines matrix with fiber. The reinforced material, GFRP rebar, has a high specific strength and excellent mechanical performance. primarily used in the utilized of pre-stressed constructions. GFRP bar properties as mentioned in the specification of the manufacturing company [15] show in (Table.2).

3.2. CFRP sheet

The Sika Wrap -300C is a unidirectional woven carbon fiber which fabric with mid-range strengths, that applied dry or wet (Table3.) Show the property.

Table3. Properties of CFRP sika wrap 300-C

Thickness (mm)	0.167
Tensile strength (MPa)	4000
Elastic modulus (MPa)	230000
Ultimate tensile strain (%)	1.7
Density (g/cm3)	1.82

3.3Adhesive Materials

Sikadur-330 is a structural epoxy paste with a high modulus and high strength that is used for external attaching carbon fiber reinforced polymers (CFRP) sheets to the bottom surface of RC slabs. (Table4.) Show the property.

4. Preparing of CFRP System in RC slabs

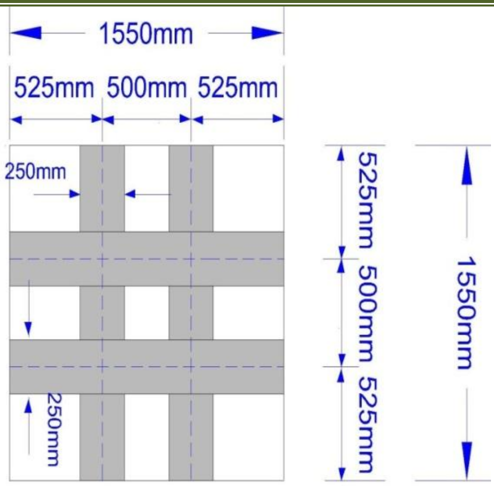
The width of CFRP strips and their space and direction changed among the specimens to discover how RC slabs strengthened with CFRP sheets. Four specimens used, each with a different CFRP configurations and an equal amount of epoxy covering the entire surface. SGC_2-B_1, SGC_1-B_1, SGC_4-B_1, SGC_3-B_1 choose to investigate how strips width and the directions (one and two) affect the dynamic response of reinforced slabs. The Slabs identification and arrangement of CFRP sheets show in (Fig.2) and (Fig.3). For gluing CFRP sheet (Sikawrap300-C) to RC slabs first grinding only the location where applied carbon sheet then clean the slab well and apply two-component epoxy (Sikadur 330) on the tensile face of the slab specimen. The epoxy blended to a consistent single color (light grey), then applied and saturated CFRP sheet with epoxy to avoid any air bubbles between the specimen surface and CFRP sheet. The described strengthening procedure conducted identically to all slab specimens. After a seven-day curing period, the epoxy strength slab reaches full strength then tested spacemen for determining the impact manner of strengthened specimen with CFRP sheet.

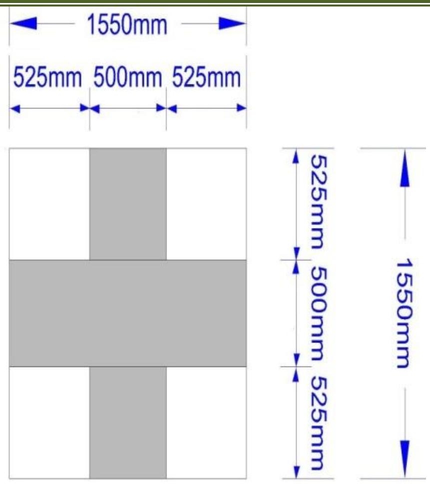
5. TEST SETUP

The drop-mass low velocity impact setup specifically designed for such investigations, as shown in (Fig.5) and (Fig.6.) Under the same loading and supporting circumstances, all specimens examined. Specimens subjected to hard impact in the middle and simply supported on all four corners to reduce the measurement of reaction forces. The slab bolted to the underlying support on all four corners with four 16mm bolts to avoid any rebounding due to impact load, and then the stand that carried the specimen bolted to the earth with a 20mm bolt to avoid any movement during the test. Two impact drops of 150 kg each administered to each specimen from a 5 meter height, resulting in a theoretical impact velocity of 9.9 m/s. The drop-mass rose to the necessary height using a crane. The crane carried a magnetic box type pML-10 with a capacity of 1000 kg and a box, which contained a man who caught the handle of the magnetic box to release the drop-mass to hit the concrete slabs with a capacity of 7.35 kJ. The drop-weight mass consists of five steel parts. The first one weighs 50 kg, while each of the other two parts weighs 25 kg, and the final lower one a spherical cone with a diameter of 200 mm at the base and 89 mm at the apex, weighs 50 kg. No damping substances used in the contact area during the tests, since damping materials diminish the strain rate accidentally. Newton's second law used to compute the impact force generated by the falling steel weight based on the average signals of two accelerometers. In order to measure the support reaction force, four dynamic load cells with a capacity of 700 kN used. The midpoint deflection was determined by using a contactless laser displacement sensor, which can precisely measure the location or displacement of the specimen without touching it. The strain rate of glass fiber reinforces polymer bar measured by using four strain gauges.

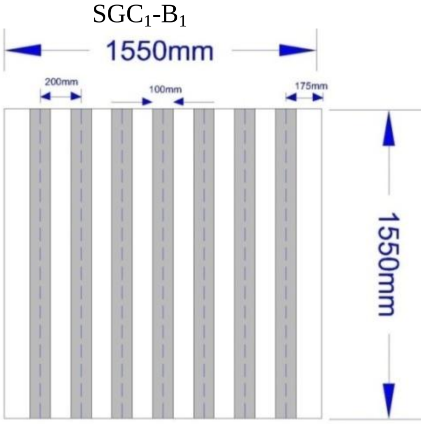
Table4. resin Remarks of Resin Characteristics

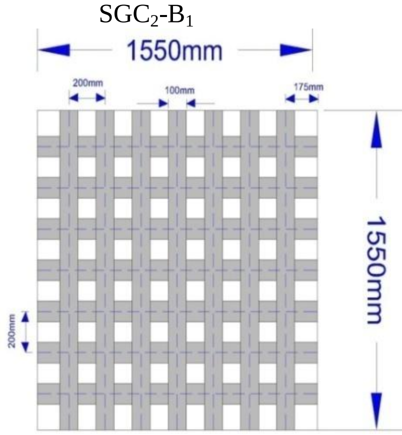
Adhesive type	Impregnating epoxy resin
Mixing ratio	Part A (resin) : part B (hardener)= 4 : 1 by weight
Tensile strength (MPa)	30
Elastic modulus (MPa)	3800
Density (kg/lt)	1.31





SGC$_1$-B$_1$ SGC$_2$-B$_1$





SGC$_3$-B$_1$ SGC$_4$-B$_1$

Fig.2. details of strength layout for slab specimens.

SGC$_1$-B$_1$ SGC$_2$-B$_1$

SGC_3-B_1 SGC_4-B_1

Fig.3. details of strength layout for slab specimens

6. RESULTS AND DISCUSSION

6.1 Deflection

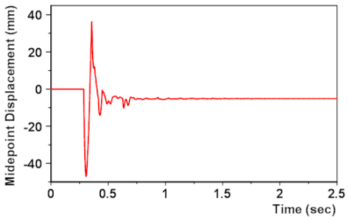
(Fig.7) and (Fig.8) show typical displacement-time histories results based on the number and width of CFRP layers. A significant variation in maximum deflections between all strength specimens and the reference slab (SG). Only the spaceman (SG) failed at the first blow, with high scabbing and penetration, while the strength slab failed at the second. This improvement could attribute to the high strength of the CFRP sheet in the specimen's initial stiffness. However, due to accumulated energy, the second strike caused stress concentration on the backside resulting in high maximum deflections. The maximum displacement of the slabs when compare as result of stripe width clear that use of distributed narrow longitudinal CFRP strips reduces the maximum displacement more than wide CFRP strips. For example, the slab with seven layers of 100 mm-wide CFRP strips in one direction SGC_3-B_1 and two directions SGC_4-B_1 had maximum displacements of (42) mm and (38) mm, respectively. While the slab with four layers of 250 mm-wide CFRP strips (SGC_1-B_1) had a maximum displacement of (44) mm. Indicating that the distributed CFRP strips more cost-effective and when compare .when compare the strength slab with non strength find a large difference between them.

Because the displacement of non-strength slab which failed at first blow was (46) mm and the higher displacement of strength slab at first blow was (15) mm at slab SGC_1-B_1 .it can be observed that the use of this strengthening method has a significant impact on decreasing the maximum displacements of slabs.

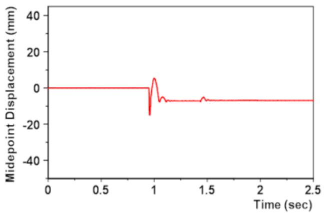
a. Drop mass **a.** **a. Drop mass** **b. Fix load cell on stand and bolted stand with earth**

c. Fix slab with stand by simple support

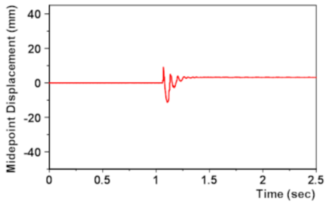
Fig.5 impact setup **Fig.6 slab fixed on stand**



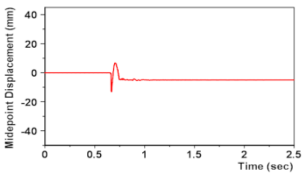
SG



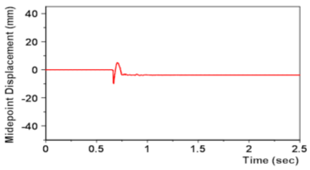
SGC_1-B_1



SGC_2-B_1

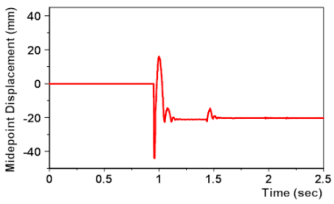


SGC_3-B_1

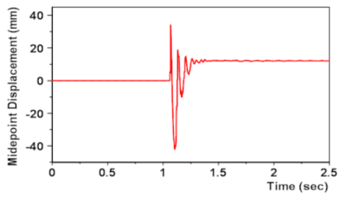


SGC_4-B_1

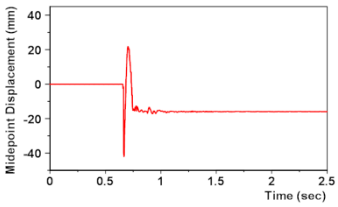
Fig.7. Mid-span displacement for first blow



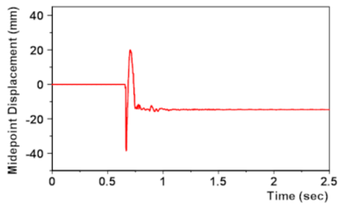
SGC_1-B_1



SGC_2-B_1



SGC_3-B_1



SGC_4-B_1

Fig.8. Mid-span displacement for second blow

6.2. Acceleration

From (Fig. 9) and (Fig.10) demonstrates the acceleration-time histories of selected slabs. Show that using of CFRP sheets to strength slabs generally results in a higher maximum acceleration. The stiffness and rigidity of concrete slabs improve by attaching CFRP sheets to the bottom of the slab, according to this study. When results compared in terms of stripe width clear that using of distributed narrow longitudinal CFRP strips raise maximum acceleration more than wide CFRP strips. For example, the maximum acceleration of a slab with seven layers of 100 mm-wide CFRP strips in one direction SGC_3-B_1 and two directions SGC_4-B_1, which measured as (395) g and (417) g at first blow and from (325)g to(370)g at second impact, respectively. While the slab with four layers of 250 mm-wide CFRP strips (SGC_1-B_1) had a maximum acceleration of (333) g at first impact and (298)g at second blow . Indicating that the distributed CFRP strips are more strength the slab especial at second impact found the effect of the strength more clear because at first blow the slab has its initial stiffness However, due to accumulated energy, the second strike caused stress concentration on the backside, resulting reduced on acceleration.

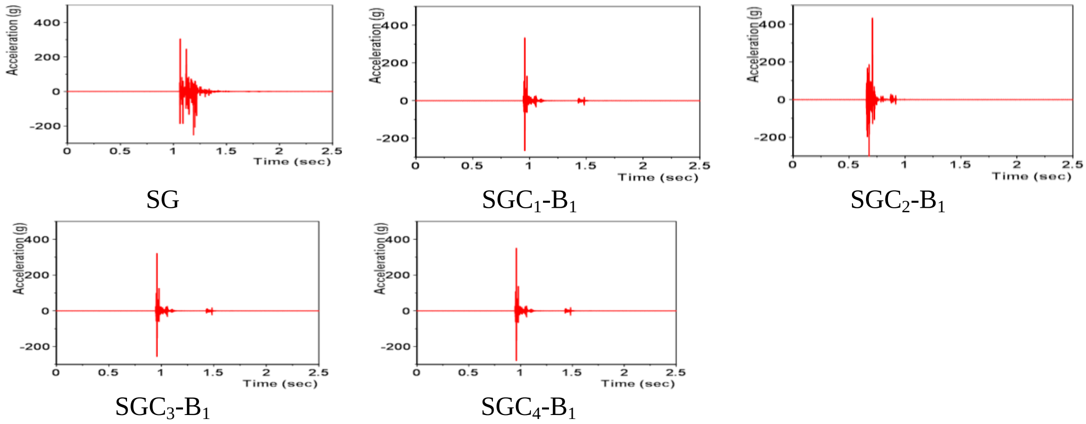


Fig.9. acceleration of slab at First Blow

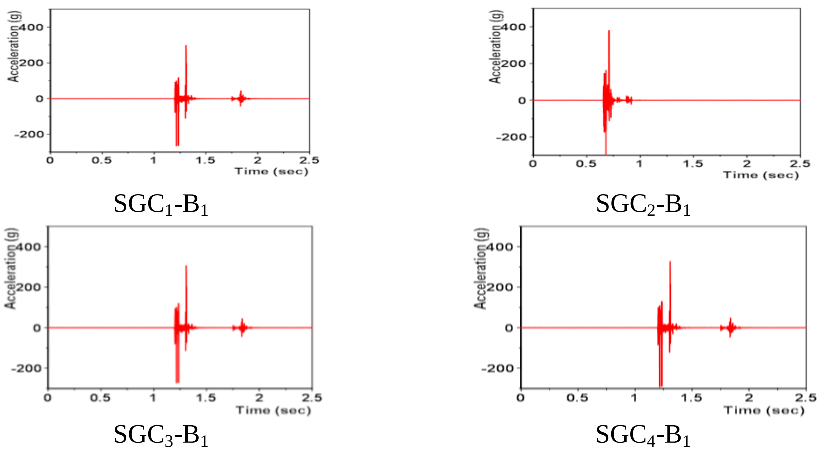
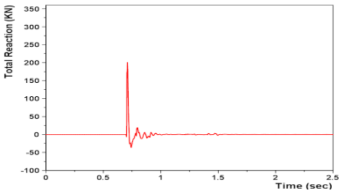


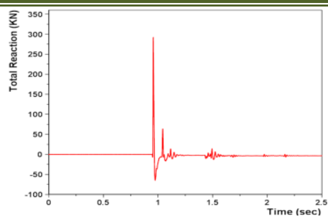
Fig.10.acceleration of slab at second blow

6.3 Total Support Reactions

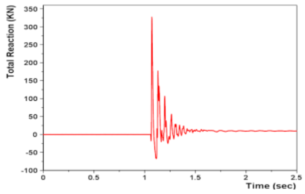
(Fig.11) and (Fig.12) show the total reaction forces measured from load cells located at the four corner supports for the first, second of specimens. In comparison with the strengthening techniques, the response force indicates a load that is not subject to loss, such as the inertial force in an impact load. When comparing the total reaction force of distributed narrow longitudinal CFRP strips to wide CFRP strips, obvious that using of distributed narrow longitudinal CFRP strips increases the total reaction force more than wide CFRP strips. For instance, a slab with seven layers of 100 mm-wide CFRP strips in one direction SGC_3-B_1 and two directions SGC_4-B_1 that measured (307) KN and (320)KN at first blow and (232)KN and (251)KN at second impact. While the slab with four layers of 250 mm-wide CFRP strips (SGC_1-B_1) had (292) KN at first impact and (237)KN at second impact .



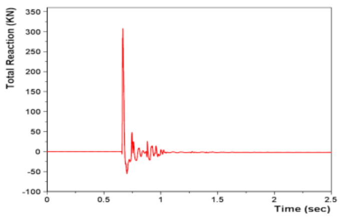
SGC



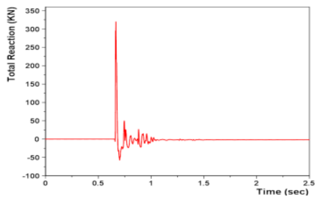
SGC$_1$-B$_1$



SGC$_2$-B$_1$



SGC$_7$-B$_1$

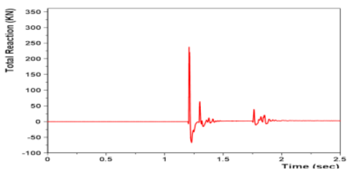


SGC$_8$-B$_1$

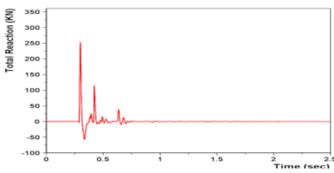
Fig.11. Total Reaction force of at first blow

6.4 Strain of Reinforcement

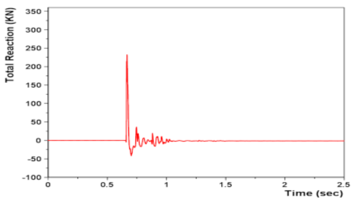
Four strain gauges embedded on the bars of each slab to study of reinforcements' strain-time history and the maximum energy absorbed by reinforcements. Typical strain-time histories of certain slabs plotted in (Fig.13) and (Fig.14). The measured strain-time history of the first drop reveals the same tendency in all specimens regardless of the strength configurations, according to the findings. The strain-time history of a strength specimen, on the other hand, influenced by strengthens in the second impact event, and this variation in behavior might be return back to the damage and associated loss of stiffness caused by the first impact event. CFRP sheets reduced reinforcing bar strain by 22% for slabs with CFRP strip. As a result increasing the number of CFRP sheet layers on the slabs' bottom face appeared better option for minimizing the maximum strain in the reinforcement bars, according to the strain measurement data.



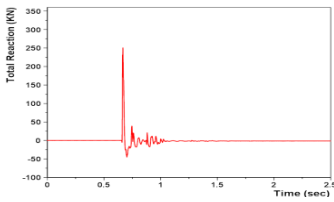
SGC$_1$-B$_1$



SGC$_2$-B$_1$

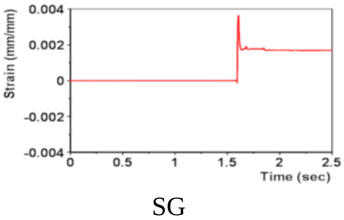


SGC$_3$-B$_1$

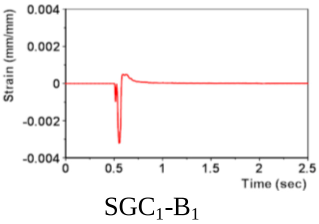


SGC$_4$-B$_1$

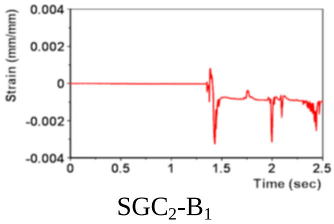
Fig.12. Total Reaction force of at second blow



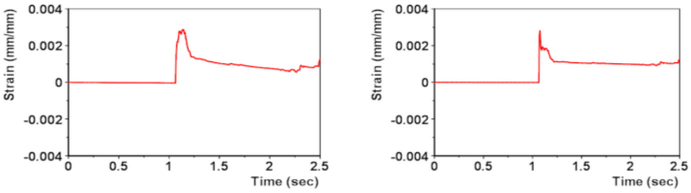
SG



SGC$_1$-B$_1$



SGC$_2$-B$_1$



SGC$_7$-B$_1$ SGC$_8$-B$_1$

Figure13. Strain of GFRP bar for slab at first blow

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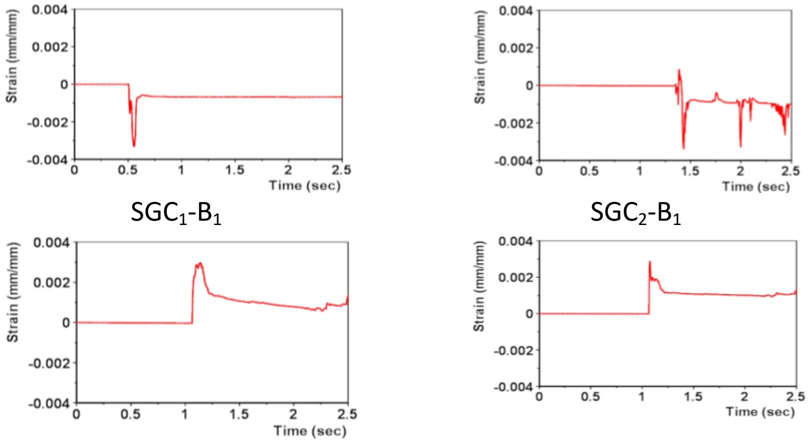

SGC$_3$-B$_1$ SGC$_4$-B$_1$

Fig.14. Strain of GFRP bar for slab at second blow

7. Conclusions

- Use of distributed narrow longitudinal CFRP strips reduces the maximum displacement more than wide strips. such as slabs SGC$_3$-B$_1$ and SGC$_4$-B$_1$ with 100 mm-width in one direction and two direction which maximum deflection measured as (42) mm and (38)mm at second blow, while the slab with four layers of 250 mm-width (SGC1-B1) had a maximum displacement of (44) mm, indicating that the less width of distributed CFRP strips with increase number are more economical.
- Comparing deflection at the first blow, the lowest maximum deflection observed in the strength specimen, which was82 percentage lower than that of the control specimen. This enhancement credited to the high strength of the CFRP sheet in the initial stiffness of the specimen.
- Strengthening of slabs by attaching CFRP sheets leads to an increase in the maximum acceleration due to the increase in stiffness as well as the rigidity of concrete slabs.
- Using CFRP strips led to lower bar strain and actual deflection at the center of slab. The decrease of the strain values means that the RC slabs strengthened to have the residual strength and they can withstand higher impact energies.
- The use of distributed narrow longitudinal CFRP strips rise the maximum acceleration more than wide CFRP strips.
- The maximum strain values measured on the test specimens strengthened with one and two direction 100 mm width CFRP strips (Specimens SGC$_3$-B$_1$ and SGC$_4$-B$_1$) on an average, 20% and 23% less than control slab.

8. Acknowledgments

This paper is part of MSC degree, which recently prepared at civil Engineering Department, College of Engineering, and Mustansiriyah University. The authors present thanks with deep appreciation to anyone who contribution, even if it was very small, during performing of this research.

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